SPECIFICATION
FOR
VACUUM PUMP
ENGINE EXHAUST SYSTEM

1. INTRODUCTION

This specification identifies the technical and performance requirements for a vacuum pump (exhauster) system for use in an altitude simulation system where the vacuum pump system will be used to simulate conditions of altitude pressure at the exhaust of a spark ignition AVGAS fueled reciprocating engine. An exhaust gas heat exchanger is located upstream of the vacuum pump inlet and is designed to cool the exhaust gas to 100°F at the inlet of the vacuum pump. The vacuum pump will be installed within a building enclosure at the FAA Technical Center, Atlantic City, New Jersey.

2.1 PERFORMANCE REQUIREMENTS

The engine exhaust vacuum system shall be capable of operating with adequate life at the design points shown in Table 1. The design points are based upon maximum engine outputs at two different altitudes.

In addition, the vacuum system shall be capable of evacuating the engine exhaust at any altitude and BHP setting below the design points. Ideally, the vacuum pump will allow engine operation at the maximum power shown from 25,000 feet to sea level.

Vacuum pump materials and seals shall be compatible with the operational environment and exhaust gas composition identified within this specification.

Although the performance specification is based upon 100°F inlet temperature to the vacuum pump, a higher inlet temperature limit is preferable.

TABLE 1
EXHAUST VACUUM PUMP DESIGN POINT

PARAMETER	400 BHP ENGINE @ 20,000 FT	300 BHP ENGINE @ 25,000 FT
EXH MASS FLOW @ PUMP INLET – LBS/MIN	50	37.5
PUMP INLET PRESSURE – IN.HG. ABS①	12.5	10.1
PUMP INLET TEMP – DEG F ②	100	100
VOLUME FLOW @ PUMP INLET - ACFM⑤	1689	1569
PUMP INLET GAS COMPOSITION ④	100% Exhaust	100%Exhaust
PUMP EXIT CONDITIONS	Ambient	Ambient
SITE ELEVATION ③	76 feet	76 feet
SITE AVG HUMIDITY	③	③

Notes:

① Assumes 10% pressure loss from engine exhaust to pump inlet. Press @ engine exhaust = 13.75 in. hg. @ 20,000 ft & 11.1 in. hg. @ 25,000 ft.

② 100°F is an assumed maximum allowable inlet temperature for the vacuum pump. Higher limits are preferable. An exhaust gas heat exchanger is located upstream of the vacuum pump and is designed to reduce engine exhaust gas temperature from 1200°F to 100°F.

③ Site elevation and average humidity based on Atlantic City, New Jersey location. Avg annual humidity is 82% morning & 56% afternoon

④ Gas composition at inlet to vacuum pump is reciprocating spark ignition engine exhaust gas with the following % volume constituents (Ref Bosh Automotive Handbook), but cooled to 100°F.

Oxides Nitrogen	.15 - .45%
Hydrocarbons	.01 - .03 %
Carbon Monoxide	2 – 5%
Carbon Dioxide	11 – 13%
Water Vapor	10 – 11%
Hydrogen	.1 - .5%
Oxygen	.3 - .5%
Nitrogen	Remainder
Lead particulates	yes

⑤ Exhaust volumetric flow is actual CFM computed at pump inlet conditions of

⑤ 100°F and pump inlet pressure shown

2.2 DESIGN POINT CALCULATIONS – 400 BHP @ 20,000 FEET

The following Table 2 summarizes design point calculations for 400 BHP at 20,000 feet altitude assuming standard day ambient conditions.

- Ambient Std Day : 13.75 IN HG @ -12.3°F (447.4°R)
- Engine Exhaust Gas Flow : 3000 lbs/hr
- Compressor Inlet Air Flow : 3340 lbs/hr
- Pressure @ Engine Exh : 13.75 in Hg Abs
- Pressure @ Vac Pump Inlet : 12.5 in Hg Abs (assumes 10% sys loss)
- Temp @ Vac Pump Inlet : 100°F assumed (higher limit desirable)
- Density ρ = 1.326 X (P in hg / T °R)
- Density ρ = .04076 lbs/ft3 @ 20,000 ft std day
- Density ρ = .07651 lbs/ft3 @ sea level std day
- Density ρ = .0296 lbs/ft3 @ 100°F & 12.5 in hg (vac pump inlet)
- Density ρ = .011 lbs/ft3 @ 1200F & 13.75 in hg (eng exh exit)
- Density ρ = .0239 lbs/ft3 @ 1200F & 29.92 in hg

TABLE 2

DESIGN POINT DATA 400 BHP AT 20,000 FEET

PARAMETER	MASS FLOW Lbs/hr	MASS FLOW Lbs/min	Ft3/min SCFM (Sea Level)	Ft3/min (ACFM) 20,000 ft
ENGINE EXHAUST FLOW	3000	50	2092	4545
COMPRESSOR INLET FLOW	3340	55.7	727.6	1366
EXH FLOW @ 1200F/13.75 IN HG	3000	50	N/A	4545
EXH FLOW @ 100F/ 12.5 IN HG	3000	50	N/A	1689
EXH FLOW @ 1200F/29.92 IN HG	3000	50	2092	N/A
INTERCOOLER COOL FLOW - REF	130	2.17	28.4	53.2

EXHAUST VACUUM PUMP DESIGN POINT

- Exhaust gas inlet at 100°F, 12.5 in hg abs
- Density ρ = .0296 lb/ft3
- ACFM = 1689 ft3/min @ 100F & 12.5 in hg abs
- Exit = 29.92 in hg abs & 59°F

2.3 DESIGN POINT CALCULATIONS – 300 BHP @ 25,000 FEET

The following Table 3 summarizes design point calculations for 300 BHP at 25,000 feet altitude assuming standard day ambient conditions.

- Ambient Std Day : 11.1 IN HG @ -30.2°F (429.5°R)
- Engine Exhaust Gas Flow : 2252 lbs/hr
- Compressor Inlet Air Flow : 2655 lbs/hr
- Press @ Engine Exh : 11.1 in hg abs
- Press @ Vac Pump Inlet : 10.1 in hg abs (assumes 10% sys loss)
- Temp @ Vac Pump Inlet : 100°F assumed (higher limit desirable)
- Density ρ = 1.326 X (P in hg / T °R)
- Density ρ = .0343 lbs/ft3 @ 25,000 ft std day
- Density ρ = .07651 lbs/ft3 @ sea level std day
- Density ρ = .0239 lbs/ft3 @ 100°F & 10.1 in hg
- Density ρ = .0089 lbs/ft3 @ 1200°F & 11.1 in hg
- Density ρ = .0239 lbs/ft3 @ 1200°F & 29.92 in hg

TABLE 3

DESIGN POINT DATA 300 BHP @ 25,000 FEET

PARAMETER	MASS FLOW Lbs/hr	MASS FLOW Lbs/min	Ft3/min SCFM (Sea Level)	Ft3/min (ACFM) 25,000 ft
ENGINE EXHAUST FLOW	2252	37.5	490.5	4217
COMPRESSOR INLET FLOW	2655	44.25	578.3	1290
EXH FLOW @ 1200F/11.1 IN HG	2252	37.5	N/A	4213
EXH FLOW @ 100F/ 10.1 IN HG	2252	37.5	N/A	1569
EXH FLOW @ 1200F/29.92 IN HG	2252	37.5	N/A	N/A
INTERCOOLER COOL FLOW – REF	130	2.17	28.4	63.3

EXHAUST VACUUM PUMP DESIGN POINT

- Exhaust gas inlet at 100°F, 10.1 in hg abs
- Density ρ = .0239 lb/ft3
- ACFM = 1569 ft3/min @ 100F & 10.1 in hg
- Exit = 29.92 in hg & 59°F

2.4 OTHER REQUIREMENTS

The engine exhaust vacuum system shall be provided as a complete package configured as follows and ready for installation at the Atlantic City New Jersey facility.

- Baseplate mounted. Base plate should not be bigger than 110"x180".
- Electric drive motor, NEMA rated Suitable for 460V, 60 hertz, 3 phrase electrical service variable speed motors with drive coupling and shaft
- Coupling guard
- The system should include a vacuum receiver vessel for knock out before passing out to the vacuum pumps.
- Pump exhaust silencer (if required).Pumps should be completely air-cooled with no water requirements. It should include inlet air filter. It should have a vacuum relief valve and check valve, high discharge temperature switch, oil sight glass, oil drain valve and low oil pressure safety switch.
- The control system should have Human Machine Interface touch screen control. It should be remotely mounted in and operated from the control room. The system should also be able to interface with our existing LabView base Data Acquisition System.
- Safety lock-outs to prevent accidental operation when not testing or engine not running.
- Installation & maintenance instructions and multi-year support contract

3. PROPOSAL REQUIREMENTS

Proposals and quotes furnished against this specification shall include the following technical data:

- Description of vacuum pump
- Envelope dimensions of assembled package
- Physical features of inlet and exit flanges
- Electrical power requirements
- Package weight
- Performance summary
- Inlet temperature limits
- Recommendations for controls

- Recommendations for installation
- Recommendations for multiple pumps and multiple stages
- Recommendations for vacuum / pressure vessel